Technology, Labor Wars, and Producer Dynamics: Explaining Consolidation in Beefpacking

James M. MacDonald and Michael E. Ollinger

Beefpacking underwent a dramatic transformation in the 1970s and 1980s, as plants got much larger and industry concentration rose dramatically. We use individual Census Bureau plant records to analyze the sources of the transformation. We find that there were modest but extensive scale economies in packing plants, covering the full range of plant sizes, and that such economies became more important throughout the period of the study. As production shifted to larger plants, we estimate that the industry's aggregate processing costs fell by 35.3% by 2002, compared to what they would have been without consolidation.

Key words: concentration, cost function, meatpacking, scale economies.

Rarely do industries, especially mature ones, consolidate as rapidly and as dramatically as beefpacking did in the 1980s. In just ten years, four-firm concentration increased from 41% of steer and heifer purchases to 78%, and plants became much larger (USDA, 2004). The industry's striking transformation led to wide controversy over the effects of consolidation on pollution, food safety, competition, rural communities, and labor relations.

This article extends our earlier research on hogs and poultry (MacDonald and Ollinger; Ollinger, MacDonald, and Madison) to analyze the sources of consolidation in beefpacking, and also extends the model used in those papers to estimate the effects of consolidation on the industry's processing costs. We start with technology, using a flexible model of plant-level costs to measure scale economies in slaughter plants and to identify changes in scale economies over time, while controlling for factor prices and the mix of meat products in plants.

Our work relies on a distinctive dataset, based on records of individual packing plants observed from 1963 through 1992 in the Longitudinal Research Database (LRD) of the U.S. Bureau of the Census. With plant-specific LRD data covering many plants in each of seven Census years, we can estimate the magnitude and extent of scale economies at a point in time, and can separate those from measures of technological change. We find that there were modest but extensive scale economies in cattle slaughter, covering the full range of plant sizes; scale became more important through time, due partly to technological change and partly to changes in the industry's wage structure that eroded pecuniary diseconomies. The LRD data also allow us to distinguish technological features such as scale economies from producer dynamics such as increases in plant size to exploit scale. With that information, we measure the effects of the industry's consolidation on processing costs.[1]

We also argue, however, that a purely technological explanation of consolidation is

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[1] Christensen and Greene pioneered our approach. Most prior meatpacking studies rely on aggregated industry time series data (Ball and Chambers; Azzam; Melton and Huffman; Morrison-Paul, 2001b). Aggregated data do not have the detail to distinguish scale-increasing technological changes from the plant size changes to exploit scale, and generally do not allow for identification of the effects of plant-specific product innovations or pecuniary scale diseconomies. Prior studies with plant-level data (Ward; Morrison-Paul, 2001a) cover one year and cannot assess the impact of changes in technology and labor relations on plant sizes.

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Table 1. Selected Characteristics of Consolidation in Cattle Slaughter

Measure	1972	1977	1982	1987	1992	1997	2002
Concentration	Percent of cattle bought by the four largest firms						
Cattle	n.a.	n.a.	32	54	64	67	69
Steers and Heifers	n.a.	n.a.	41	67	78	80	79
Plant size (head/year)	Percent of annual slaughter, by plant size						
<9,999	5.0	3.5	3.1	2.0	1.6	0.9	0.7
10,000–49,999	18.4	14.2	11.2	6.7	4.0	2.8	1.5
50,000–99,999	21.1	20.5	12.1	8.3	3.9	3.2	1.3
100,000–249,999	26.2	30.1	20.4	17.8	15.4	10.8	7.1
250,000–499,999	<u>29.2</u>	19.5	25.0	14.0	13.8	16.7	16.8
500,000–999,999	d	12.2	<u>28.2</u>	26.6	33.7	15.7	14.2
>999,999	d	0.0	d	24.5	27.8	49.8	58.4
Product mix	Percent of boxed beef in SIC 20111 value of shipments						
Boxed beef share	15.5	30.1	39.5	43.2	56.2	55.4	59.7
Hourly wages	Nominal payroll per production worker hour, SIC 2011						
Large plants	5.33	8.44	10.04	8.50	8.65	9.32	11.12
Small plants	4.40	6.50	9.38	8.38	8.67	9.62	12.83

Sources: Plant size and concentration are from the USDA Grain Inspection Packers and Stockyards Administration. Product mix and hourly wages are from the U.S. Census Bureau.

Note: In cells marked "d," data are combined with the cell above, which is underlined, in order to comply with confidentiality restrictions. Large plants have 1,000 or more workers, while small plants have less than 1,000.

incomplete, for three reasons. First, complementary organizational changes in cattle feeding provided packing plants with the steady large flows of livestock needed to realize the scale advantages of plant size. Second, competitive price pressures, arising from the undifferentiated nature of plant output as well as from the presence of well-informed meat buyers and cattle sellers, accelerated the industry's consolidation. Third, declining beef demand combined with sharply increased plant sizes to drive the dramatic increase in industry concentration.

Consolidation in Beefpacking

We start by summarizing the industry's dramatic consolidation, relying on two data sources. The Grain Inspection, Packers and Stockyards Administration (GIPSA) of the U.S. Department of Agriculture (USDA) documents the physical flows of livestock to packing plants, relying on required reports filed by firms that purchase at least $500,000 of livestock in a year. Public Census of Manufactures data detail changes in the industry's product mix and average wages.

Four-firm concentration in the industry (CR4) increased dramatically between 1982 and 1992, from 32 to 64 in cattle and from 41 to 78 in steers and heifers (table 1); concentration stabilized after 1992. CR4 increases of this speed and size are extremely unusual; indeed, the Census Bureau has been publishing concentration data for manufacturing industries since 1947, and no published industry shows as great an increase in any ten-year period as that traced here.[2]

CR4 increases coincided with sharp increases in plant sizes. In 1972, plants handling less than 250,000 head of cattle per year accounted for over 70% of all cattle slaughter, with almost half of that in plants handling less than 100,000 head (table 1). Thirty years later, in 2002, plants handling over 500,000 cattle a year accounted for over 70% of slaughter, with most of that in plants handling more than a million head, while plants handling less than 100,000 held less than 4% of total slaughter. Most of the transformation occurred between 1977 and 1992, with a continuing shift to the largest plants after 1992.

Two Complicating Factors: Product Mix and Wages

The sharp increases in plant size suggest that scale economies may have been an important factor in consolidation. But two other important developments—changes in product mix

[2] Census industry definitions capture established products. Sharp concentration increases do occur frequently among producers of new products, as closely held process innovations developed by a few firms allow leaders to emerge (Gort and Klepper), but dramatic concentration increases in long-established industries are quite rare.

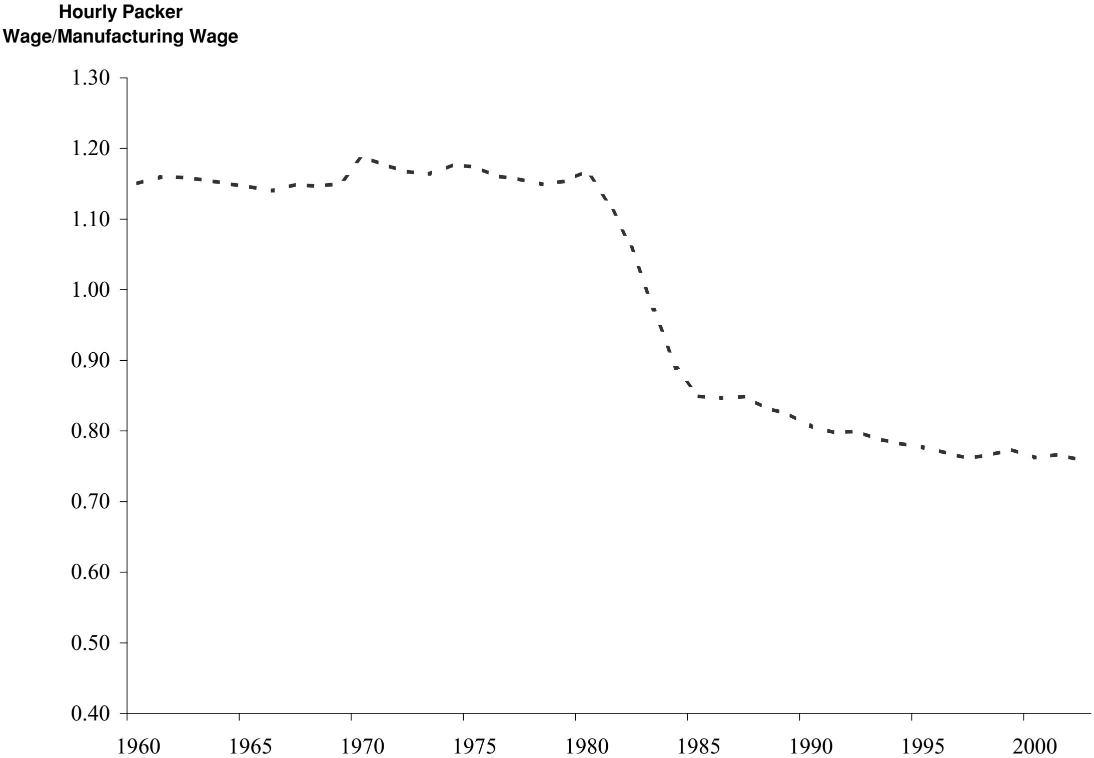

Figure 1. Relative hourly production worker wages in meatpacking

and in wages—had major coincident impacts on the industry; because each complicates the identification of scale economies, it is important to account for them.

Most packers in the early 1970s shipped cattle carcasses to processors, wholesalers, or retailers for processing into retail cuts. Today, many cut carcasses into wholesale and retail cuts of meat on fabrication lines, then vacuum-wrap the cuts and ship boxes of cuts to buyers. This "boxed beef" accounted for only 9% of packer shipments in 1963, but rose steadily to just over half by 1992, and has stabilized there since (table 1). Plants shipping boxed beef use more labor, capital, and packaging and thus have noticeably higher total costs. But because larger plants produce greater proportions of boxed beef, omission of product mix measures can also lead to biased estimates of scale economies.[3]

In 1978, unions enrolled nearly 45% of the workforce in the meat products sector, which includes livestock and poultry slaughter and processing industries, and unionized workers realized a wage premium of 29%, on average, over non-union meat products workers (Belman and Voos). By 1980, unionized firms began to press for large reductions in base wages, from $10.69 an hour to $8.25, consistent with wages in non-union plants. After a series of strikes and plant closings, union coverage had by 1987 fallen to only 21% of the workforce, and the union wage premium disappeared (Belman and Voos).

Figure 1 summarizes the effects of the upheaval on industry wages, comparing annual Bureau of Labor Statistics data on mean hourly production worker wages in livestock slaughter plants with those in all of manufacturing. Between 1960 and 1980, meatpacking wages remained consistently in a range 14–18% above manufacturing wages. But four years of major labor battles resulted in plunging wages, which fell to 12% below all-manufacturing wages by 1984. Relative wages continued a gradual steady decline thereafter, to 25% below all-manufacturing wages by 2002.

The wage upheaval fell more heavily on large plants (table 1), which were more likely

[3] Ollinger, MacDonald, and Madison provide a detailed evaluation of the impact of measures of product mix on estimates of scale economies in livestock and poultry processing.

Table 2. Disappearing Size Premia in Beefpacking Wages

Variables	1963	1967	1972	1977	1982	1987	1992
	Coefficients and standard errors (in parentheses)						
Intercept	−0.105	0.066	0.317	0.765	1.469	1.983	2.207
	(0.073)	(0.072)	(0.082)	(0.120)	(0.175)	(0.126)	(0.164)
Plant size	0.093	0.090	0.094	0.078	0.059	0.013	0.001
	(0.008)	(0.008)	(0.008)	(0.011)	(0.016)	(0.011)	(0.017)
Corn Belt	0.183	0.173	0.135	0.257	0.006	0.008	−0.045
	(0.031)	(0.034)	(0.038)	(0.048)	(0.086)	(0.062)	(0.068)
Plains	0.077	0.009	−0.067	0.089	−0.154	−0.099	−0.151
	(0.034)	(0.038)	(0.041)	(0.050)	(0.083)	(0.060)	(0.069)
West	0.316	0.252	0.237	0.356	0.078	0.022	−0.023
	(0.034)	(0.037)	(0.042)	(0.051)	(0.093)	(0.647)	(0.078)
R^2	0.31	0.33	0.34	0.27	0.10	0.05	0.19

Source: LRD, U.S. Bureau of the Census.

Notes: The table reports a separate regression for each year. Dependent variable is log of average hourly production worker wages at the plant (annual payroll, divided by hours). Plant size is the log of the number of cattle slaughtered in the year. Regional dummies represent plants located in the Plains (TX, OK, KS, CO, NE, ND, SD), West (all states west of Plains), and Corn Belt (IA, IL, In, MI, MN, MO, OH, WI), with the rest of the country as the base. Regressions also include measures of product and input mix (defined in text).

to be unionized, and hence may have affected scale-cost relations in the industry. Since changes in the industry's wage structure can affect the estimation and impact of technological scale economies, we look more closely at the issue below.

Wages and Plant Size in Cattle Plants

Average meatpacking wages in table 1 and figure 1 are aggregated across several slaughter industries, regions, and plant size categories. Because of the importance of the issue to our later analysis, we look at wages more closely, using LRD data on annual production worker payroll and hours in individual slaughter plants. Specifically, in each Census year, we regressed the log of each plant's mean hourly wages on plant size (the log of the number of cattle slaughtered in that year) and regional dummy variables for the Corn Belt, the Plains, and the West. The models also included a measure of product mix, one minus the share of whole and half carcasses in output, and a measure of input mix, the share of meat inputs in combined expenditures on meat, and animal inputs. Results are reported in table 2.

Controlling for location, product mix, and input mix, coefficients on plant size are positive and highly significant through 1982. The size-wage elasticity, just over 0.09 from 1963 through 1972, fell to 0.059 by 1982 and then disappeared by 1992—the coefficient on size in 1992 is very small and not significant. Large plants in the 1970s apparently faced pecuniary diseconomies of scale, and the disappearance of wage-size premia coincided with consolidation.[4]

Wages also showed strong regional effects before 1980, with wages in Corn Belt and Western plants far exceeding those paid in Plains plants (TX, KS, CO, NE) and in the rest of the country (table 2). After 1980, wages in the Corn Belt and the West moved into parity with the rest of the country, but plants in the Great Plains continued to realize a 10–15% advantage over other regions. During the industry's consolidation, production also shifted to the Plains, and the largest plants are all located in Plains states. In our analysis of scale economies, we will need to account for the coincident effects of changes in the wage structure.

The Model and the Data

The shift to large plants suggests that scale economies may have been an important factor in consolidation. We use a model which is designed to estimate the extent of scale economies over a wide range of plant sizes, identify scale-increasing technological changes, account for changing product mix, and identify the effects of labor market shifts on plant costs and scale measures.

We estimate a translog cost function, with arguments as follows:

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[4] Coefficients on product and input mix (unreported) were small and not statistically significant.

$$
\begin{aligned}
(1)\quad \ln C = {} & \alpha_0 + \sum \beta_i \ln P_i \\
& + \frac{1}{2} \sum \sum \beta_{ij} \ln P_i \ln P_j \\
& + \gamma_1 \ln Q + {}^1\!/\!_2 \gamma_2 (\ln Q)^2 \\
& + \sum \gamma_{1i} \ln Q \ln P_i + \sum \delta_k \ln Z_k \\
& + \frac{1}{2} \sum \sum \delta_{kl} \ln Z_k \ln Z_l \\
& + \sum \sum \delta_{ik} \ln P_i \ln Z_k \\
& + \sum \delta_{1k} \ln Q \ln Z_k + \sum \alpha_n T_n \\
& + \sum \sum \alpha_{in} \ln P_i T_n \\
& + \sum \alpha_{1n} \ln Q T_n \\
& + \sum \sum \alpha_{kn} \ln Z_k T_n
\end{aligned}
$$

where C is total cost (ln is the log operator), the P_i are factor prices (for four inputs: labor, animal and meat materials, capital, and other materials), Q is output, the Z_k are plant characteristics, and the T_n are dummy variables for each Census year, with 1992 as the base.

The cost function is estimated jointly with the optimal, cost-minimizing input demand, or cost-share, equations. Those equations are the derivatives of total cost with respect to each input price, and share parameters with the cost function:

$$
\begin{aligned}
(2)\quad & (\partial \ln C)/(\ln P_i) \\
& = (P_i X_i)/C = \beta_i + \sum \beta_{ij} \ln P_j \\
& \quad + \gamma_{1i} \ln Q + \sum \delta_{ik} \ln Z_k \\
& \quad + \sum \alpha_{in} T_n
\end{aligned}
$$

where the X_i are input quantities. Since variables were normalized (divided by their sample mean values before estimation), first-order terms (the β_i) can be interpreted as the estimated cost-share of an input at mean values of the right-hand-side variables. Because of likely cross-equation correlation in the error terms, we follow standard practice by using a nonlinear iterative seemingly unrelated regression procedure for estimation.

Variables and Data Sources

All variables, except for capital rental prices, are derived from the LRD maintained at the Center for Economic Studies of the U.S. Census Bureau. The LRD consists of observations on individual Census of Manufactures establishments in each Census year from 1963 through 1992. Each record provides detailed information on product types, quantities, and revenues, material input quantities and expenditures, employment and payroll, and ownership and location. Our dataset, which includes 2,541 plant observations, consists of livestock slaughter plants with at least 20 employees, whose primary product class was SIC 20111 (beef), who reported complete input and output data, and whose records met consistency requirements (e.g., between cattle and meat inputs and meat outputs).

LRD files report physical output quantities for carcasses, hides, primal and fabricated cuts (boxed beef), ground beef, and byproducts. In principle, we could have represented output (Q) in the cost function as a vector, with each vector element representing separate LRD products. But since few plants produce all products, and logs are undefined at zero, the translog functional form cannot directly be adapted to a multiproduct approach. Instead, we define a single output measure Q to be pounds of all meat products shipped from a plant (all categories in SIC 2011). We then add production characteristics to the model (the Z_k variables) to account for plant complexity.[5]

We define product mix (PMIX) to be the share of noncarcass shipments in output—that is, Q minus pounds of carcass shipments (SIC seven-digit product classes 2011112 and 2011114), divided by Q. PMIX will always be defined in the translog, as carcasses are never 100% of output. Because hide and byproducts are produced in nearly fixed proportions to the number of cattle slaughtered, those products account for nearly constant shares of total output. As a result, PMIX varies directly in proportion to the share of boxed and ground beef in a plant's output. Expanded boxed and ground beef shares in production will lead to increased use of labor, capital, and materials.[6]

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[5] Our approach follows one used for transportation cost functions, which often specify output in ton-miles, and then include measures of route and output characteristics, because ton-miles can be produced in many ways. Output may be routed to many locations, instead of a few, or it can be routed in many small deliveries, instead of a few large shipments (Allen and Liu).

[6] We tested alternatives, including a multi-product cost function (substituting low, positive values for zero volumes); other product characteristic measures, such as one minus boxed beef; and the relative value of output, based on revenue per pound of meat. All gave similar qualitative results, but our final choice provided the best fit to the data and a more direct interpretation.

We define input mix (IMIX) to be the share of livestock in combined livestock and purchased meat input costs. Some plants purchase additional carcasses from other slaughter plants as inputs to processing activities. Plants with more purchased meat inputs may have different cost structures than plants with less diversified input flows. We also use a dummy variable (EST1), set equal to one for single establishment firms.

Total cost (COST) is the sum of labor, meat, material, and capital input expenses, and we define four factor prices. Meat input prices (PMEAT) are defined as expenses for meat and animal inputs, divided by total pounds of meat and animal inputs. The price of labor (PLAB) is total plant labor costs (payroll plus supplemental labor expenses) per employee.[7] The materials price (PMAT) is total annual expenses for packaging, energy, and other nonanimal and nonmeat materials, divided by pounds of animal and meat inputs. The price of capital (PCAP) is the weighted sum of machinery and structures rental values, where the weights are their respective book values. Annual capital rental prices are calculated by the Bureau of Labor Statistics separately for buildings and for machinery in the two-digit Food and Kindred Products Industry Group (U.S. Department of Labor). The measures include components for depreciation, changes in asset prices, and taxes. Since the weights (book values of structures and equipment) differ across plants, capital prices are plant-specific.[8]

Modeling Output, Scale and Scope, and Technological Change

The estimated cost function yields a natural measure of scale economies, the elasticity of total cost with respect to output, Q:

$$(3)\qquad \varepsilon_{CQ} = (\partial \ln C)/(\partial \ln Q) = \gamma_1 + \gamma_2 \ln Q + \sum \gamma_{1i} \ln P_i + \sum \delta_{1k} \ln Z_k + \sum \alpha_{1n} T_n.$$

[7] We used this measure instead of hourly production worker wages (used as the dependent variable in the table 2 wage regressions, and highly correlated with *PLAB*) because it includes nonwage compensation and covers all workers, not just production workers.

[8] The capital price used here differs from that used in earlier papers (MacDonald and Ollinger; Ollinger, MacDonald and Madison), which added the ratio of new investment to assets as a way to capture costs of adjustment. The measure used here is more transparent and theoretically appropriate, but its use does not substantively alter the results here or in the earlier studies.

The first-order term, γ_1, can be interpreted directly as a 1992 estimate of scale economies at the sample mean plant size. Parameters on the T variables (the α_{1n}) show how the elasticity varies over time, while that on the Q term (γ_2) allows ε_{CQ} to vary with changes in plant size.

We observe cattle slaughter plants in seven Census years: 1963, 1967, 1972, 1977, 1982, 1987, and 1992. The model allows for technological change by entering separate temporal intercept shifts, and by allowing all first-order parameters to vary over time through interaction terms with each of the six different temporal dummy variables.

We argued above that the major period of the industry's consolidation ended around 1992, the last year of our LRD plant-specific data. For that reason, we use 1992 as the base year for our temporal intercept shifts, and hence the coefficients on all temporal shifts are relative to 1992. For consistency and clarity of presentation, we also report elasticities using a 1992 technology base and 1992 factor prices, and report deviations from that base as appropriate.

Model Selection and Evaluation

We aim to use the model described above to identify scale relations in slaughter plants, and to estimate the effects of industry consolidation on costs. But first we provide evidence that the model can provide an accurate representation of the industry. We apply a series of tests designed to choose the best model among a variety of specific choices, and then evaluate model outcomes in the light of economic theory and prior industry evidence.

Model Selection

The model summarized in equation (1) is our most general functional form. We tested the fit of the model against several alternatives, closely following the strategy outlined in our earlier papers (MacDonald and Ollinger; Ollinger, MacDonald, and Madison). We started with the most restrictive functional form, one that allowed for no technological change and no plant characteristics (omitting all T and Z variables from equation 1); the most restrictive form was decisively rejected in favor of a model with PMIX, IMIX, and their interactions. That model was in turn decisively rejected in favor of the general model defined in equation (1), which added technological change in the form of all T variables and

Table 3. Beefpacking Cost Function Parameters: First–Order Terms and Year Shifts

Variables	Base (1992)	Temporal Shifts from 1992 Base 1987	1982	1977	1972	1967	1963
Intercept	−0.3668	0.0914	0.0317	0.1083	0.1098	0.0509	0.0743
	(0.0376)	(0.0482)	(0.0462)	(0.0431)	(0.0421)	(0.0401)	(0.0399)
PLAB	0.0798	0.0043	0.0143	0.0205	0.0197	0.0179	0.0130
	(0.0053)	(0.0062)	(0.0062)	(0.0061)	(0.0060)	(0.0056)	(0.0055)
PMEAT	0.8359	−0.0015	−0.0009	0.0066	−0.0132	0.0179	0.0038
	(0.0086)	(0.0102)	(0.0100)	(0.0095)	(0.0097)	(0.0056)	(0.0090)
PMAT	0.0480	−0.0015	−0.0022	−0.0012	0.0087	0.0093	0.0050
	(0.0036)	(0.0043)	(0.0042)	(0.0040)	(0.0040)	(0.0038)	(0.0038)
PCAP	0.0363	−0.0013	−0.0112	−0.0260	−0.0151	−0.0228	−0.0219
	(0.0100)	(0.0117)	(0.0117)	(0.0113)	(0.0114)	(0.0106)	(0.0105)
Q	0.9242	0.0086	0.0099	0.0170	0.0268	0.0458	0.0434
	(0.0140)	(0.0167)	(0.0162)	(0.0155)	(0.0149)	(0.0146)	(0.0147)
PMIX	0.0451	0.0117	−0.0116	0.0069	−0.0133	−0.0158	−0.0203
	(0.0117)	(0.0115)	(0.0113)	(0.0105)	(0.0105)	(0.0104)	(0.0106)
IMIX	−0.0395	0.0180	0.0088	0.0133	0.0250	0.0199	0.0236
	(0.0091)	(0.0102)	(0.0096)	(0.0090)	(0.0087)	(0.0085)	(0.0085)

Note: Results of estimation of translog cost function for beefpacking plants, 1963–92. Estimated standard errors are in parentheses. Base coefficients can be interpreted as elasticities at the sample means, while temporal shifts capture changes in those elasticities in earlier years.

their interactions (as well as EST1 and interactions between that dummy and all first-order terms).[9] Our tests show that it is important to allow for product and input mix, ownership type, nonhomothetic production, and technological change in production parameters. Parameter estimates from our best-fitting model are reported in tables 3 and 4: table 3 reports first-order coefficients for 1992 and all time shifters for earlier years, while table 4 reports coefficients on quadratic and interaction terms.

Evaluating Model Estimates: Input Demands

In table 5, we report estimates of factor shares, own-price demand elasticities, and Morishima elasticities of substitution (Blackorby and Russell), all calculated at mean 1992 sample values. Own price demand elasticities for labor (−0.52), capital (−0.79), and other materials (−0.23) are all negative and of reasonable magnitude. The own price demand elasticity for animal and meat inputs (0.03) is very close to, and not significantly different from, zero. Although we rejected strong partial separability (footnote 9), changes in cattle prices, holding meat output constant, have essentially no observable effect on cattle demand; that is, there is no systematic effect of cattle prices on meat yields in our sample, a not unreasonable finding.

Factor shares in beefpacking are highly skewed, with animal inputs accounting for just over 85% of costs at 1992 means. The animal share is a distinctive feature of meatpacking industries, because a material input rarely accounts for such a large share of costs. A large cattle share limits the effects of scale economies on total costs since the processes that drive meatpacking scale economies are limited to the cooperating inputs of labor, capital, and other materials that together make up only a fifth to a tenth of total costs.

Evaluating the Model: Cost Predictions

We next evaluated several cost predictions in order to judge model soundness. First, estimated marginal costs meet a regularity condition—they are positive for all observations. Next, consider the estimated effects of product mix. The first-order coefficient on PMIX (the noncarcass share of plant output) is positive and statistically significant, while that on its square is positive and highly significant

[9] We tested a series of alternatives. All interaction terms involving *PMIX* and *IMIX* were dropped, but the restrictions were strongly rejected—it is important to account for those differences across plants. We tested for homotheticity by forcing factor shares to be invariant to output (dropping interaction terms between output and factor prices), and our tests decisively rejected homotheticity. Finally, we tested whether livestock is separable from other inputs in the production process, a restriction that is a point of controversy in the literature on food processing (Wohlgenant). Following Norsworthy and Malmquist, we imposed strong partial separability between livestock and other inputs by dropping all interaction terms involving animal input prices, but our tests rejected that model.

Table 4. Beefpacking Cost Function Parameters: Interaction Terms

	Interacted with:							
Variable	PLAB	PMEAT	PMAT	PCAP	*Q*	PMIX	IMIX	EST1
PLAB	0.0262	−0.0676	0.0038	0.0377	−0.0202	0.0045	0.0046	−0.0142
	(0.0032)	(0.0028)	(0.0010)	(0.0036)	(0.0008)	(0.0004)	(0.0003)	(0.0025)
PMEAT		0.1511	−0.0406	−0.0429	0.0262	−0.0032	−0.0062	0.0126
		(0.0047)	(0.0014)	(0.0049)	(0.0012)	(0.0006)	(0.0006)	(0.0041)
PMAT			0.0370	−0.0002	0.0016	−0.0004	−0.0009	0.0032
			(0.0007)	(0.0017)	(0.0005)	(0.0003)	(0.0002)	(0.0017)
PCAP					−0.0077	−0.0008	0.0020	−0.0016
					(0.0014)	(0.0007)	(0.0006)	(0.0047)
Q					0.0117	−0.0018	−0.0015	−0.0096
					(0.0031)	(0.0014)	(0.0012)	(0.0075)
PMIX						0.0085	0.0014	−0.0004
						(0.0017)	(0.0008)	(0.0048)
IMIX							−0.0061	−0.0004
							(0.0018)	(0.0043)

Note: Quadratic (on diagonal) and interaction terms from estimation of translog cost function.
Estimated standard errors are in parentheses.

(tables 3 and 4). Holding output constant, more processing leads to higher costs, with reasonable magnitudes. At a large 1992 plant (1.35 million head of cattle), a move from minimal to extensive fabrication—raising PMIX from 0.25 to 0.90—raises predicted total costs by 7%. Because livestock purchases, which are unaffected by fabrication, account for a predicted 93% of total costs at a large plant with minimal fabrication, the implied effect on processing costs, exclusive of livestock purchase expenses, is quite large, a 70% increase, with the livestock share falling to 88%.

Finally, we compared predicted costs to other estimates. Two economic/engineering studies have developed estimates of unit processing costs, exclusive of animal purchase expenses, in cattle slaughter plants (Ward). Using parameters from those studies and factor price data for 1988, Ward reported cost estimates in the range of $56–$60 per head for the largest combination slaughter-fabrication plants operating at full capacity.

We estimated processing costs, exclusive of animal purchase expenses, by first estimating total costs at a large (1.35 million head) slaughter-fabrication plant, assuming mean 1992 values for factor prices, PMIX, and IMIX. We then used the predicted animal share of total costs to estimate total processing costs at a large plant, and then divided by the number of cattle to estimate unit processing costs of $69.50 per head. Our estimates are based on actual year-round experience, while Ward's estimates are based on best practice at full capacity. In particular, Ward's assumptions (20 hours per day in two shifts, 6 days per week, 300 head per hour) imply 1.8 million head per year. That is well outside the range of our data, but at 1.8 million head per year, our estimated processing costs would fall to $63.73 per head. Moreover, if we had used 1987 factor prices instead of 1992, cost would fall further, to $58. In short, predicted unit costs from this model are quite consistent with those reported elsewhere.

Table 5. 1992 Mean Input Shares and Elasticities

Measures	PLAB	PMEAT	PMAT	PCAP
Input shares	0.0635	0.8545	0.0515	0.0305
Own price demand elasticity	−0.524	0.031	−0.230	−0.792
Substitution elasticities (Morishima)				
PLAB	0	−0.457	0.609	1.641
PMEAT	0.316	0	0.040	−0.429
PMAT	0.358	0.244	0	0.285
PCAP	1.510	0.792	0.838	0

Note: Calculations use mean 1992 data values and parameters from tables 3 and 4.

Table 6. Measures of Scale Economies in Beefpacking

Scale Vintage	Size–Wage Elasticity	Plant Size (Cattle/Year)				
		50,000	175,000	425,000	850,000	1,350,000
				Cost/head index		
1992	0.0	1.104	100.0	94.3	90.6	88.5
1977	0.0	1.082	100.0	95.8	93.1	91.7
1963	0.0	1.045	100.0	98.0	97.0	96.7
1977	0.094	1.067	100.0	96.5	94.0	92.7
1963	0.094	1.025	100.0	98.7	97.4	97.0
				Cost elasticity		
1992	0.0	0.915	0.929	0.939	0.947	0.952
1977	0.0	0.932	0.946	0.956	0.964	0.969
1963	0.0	0.958	0.972	0.982	0.990	0.995

Note: Estimates derived from model summarized in tables 3 and 4, with factor prices and plant characteristics set to mean 1992 values for multi-establishment firms.

Economies of Scale in Cattle Slaughter

We now turn to the primary focus of our study. The first-order cost elasticity, 0.924, is significantly below one and indicative of economies of scale in 1992 at sample means (table 3). The temporal shifts reported in table 3 are all positive, and grow steadily larger as one moves back toward the 1960s. The coefficients are statistically significant for earlier years, and technological change has clearly been scale-increasing.

Table 6 provides more detailed evidence. We report indexes of predicted average total cost (per head) and cost elasticities for five representative plant sizes, and show how each varies with changes in technology and wage premia. The smallest plant, 50,000 head per year, represented an important share of output in earlier years (table 1). A plant of 175,000 head represents many commercial plants in the 1970s. The next two (425,000 and 850,000 head) approximate mean plant sizes among the four largest packers in 1980 and 1992, respectively (USDA 2004). The largest (1.35 million head) would be a very large plant in 1992 or today.

We report indexes of average total cost (per head) in table 6, based on predicted values from our estimated model, using mean 1992 values for factor prices, PMIX, and IMIX, and with EST1 set to zero. The top row shows how average costs varied with plant size under 1992 scale relationships. Scale economies are modest but extensive; the largest plant's average costs are 11.5% below the small commercial plant (175,000 head), and 2.0–6.0% less than mid-sized commercial plants. The largest plants have much greater proportionate cost advantages if we restrict the comparison only to processing costs, exclusive of animal purchase expenses (not shown in the table)—15% per head below the next largest plant, and 38% below plants at 425,000 head.

Technological change had important effects on scale economies. The second row reports indexes with 1992 factor prices and plant characteristics, but with 1977 scale relations, while the third row uses 1963 scale relations. Average costs are noticeably flatter under the earlier technologies, particularly in 1963, when large plants had much more limited advantages over smaller.

We assess the effects of wage premia on scale advantages in the next two rows. We used a size–wage elasticity of 0.094 (from table 2) to calculate wage premia at each plant relative to the smallest, and then used predicted labor shares (from the cost function) to calculate the effect of wage premia on plant costs. The effect of size-related wage premia is to further reduce the importance of scale economies, and the cost advantages of large plants. However, the effects are quite modest, because labor's share is small.[10]

We report cost elasticities in the bottom three rows of table 6. With 1992 factor prices and technology (top row), values of ε_{CQ} range from 0.915 at the smallest plant to 0.952 at

[10] Regional wage effects also matter. Plains plants maintained a wage advantage, of about 14% in 1992, over plants in other regions of the country (table 2). All plants with at least 850,000 head were in four Plains states in 1992—Colorado, Kansas, Nebraska, and Texas—while plants elsewhere in the country are much smaller, with few exceeding 425,000 head. If smaller plants also faced a regional wage disadvantage compared to large Plains plants, their 1992 unit cost indexes would rise to 102 (for a 175,000 head plant) and to 96 (for the 425,000 head plant) compared to 88.5 for the largest plant, thus accentuating the scale advantage held by the largest plants.

the largest. These estimates indicate that scale economies were not exhausted even at the largest plants, suggesting continuing pressures to expand plant sizes after 1992. The bottom row shows the effects of technological change: cost elasticities move much closer to one (constant returns) in the 1963 technology, and technological change between the 1960s and 1992 was therefore scale-increasing.

The evidence on scale economies is clear. Technology changed, prior to the industry's consolidation, and beefpacking became subject to modest but extensive plant-level scale economies, arising in slaughter and fabrication processes that made more intensive use of inputs in larger plants. Labor market upheavals that led to the disappearance of wage-related pecuniary diseconomies provided a further small spur to scale economies. With extensive scale economies, the industry's subsequent consolidation into larger plants led to substantial declines in processing costs, a subject to which we now turn.

Scale Economies and the Effects of Consolidation on Industry Costs

There is a distinct difference between the existence of scale economies, and changes in plant sizes to exploit them (Christensen and Greene). In 1977, almost 70% of cattle moved through plants handling less than 250,000 cattle a year (table 1), too small to exploit scale economies available in 1977. The pattern stands in contrast to our findings for hog slaughter (MacDonald and Ollinger), where the industry's largest plants were always large enough to realize extant scale economies, and where plant sizes changed quite rapidly in response to new scale economies.

Plant sizes increased sharply during the industry's dramatic consolidation in the 1980s (table 1). We next estimate the effects of that consolidation on industry costs, while holding factor price and product mix measures constant in order to focus solely on the effects of plant size and scale economies. We focus on processing costs, exclusive of animal purchase expenses, in order to facilitate comparison with other analyses and because scale economies arise in processing functions.

We used parameters from our cost model to generate estimates of per-head processing costs for plants of each size represented in our sample. First, we set EST1 to zero, and inserted 1992 sample means for factor prices, PMIX, and IMIX into the model, to generate predicted total costs at each sample plant. Next, we used the predicted animal share to subtract animal purchase expenses, and then divided total processing costs by cattle volume to arrive at a predicted per head processing cost for each plant. We then calculated the industry's weighted average processing cost, where the weights are each plant's share of total slaughter. The result, reported in table 7, was \$95.83 per head.[11]

We then estimated what processing costs would have been in the absence of consolidation—that is, if the industry in 1992 had the same distribution of plant sizes as in 1977. To do so, we reweighted the estimate in table 7, using as weights the share of each plant size in 1977, rather than 1992, production.[12] The industry's per-head processing cost rises sharply, to \$132.18 (1992\$), reflecting the much larger share of 1977 production that was in smaller plants. Hence, we estimate that the shift in the plant size distribution between 1977 and 1992 reduced processing costs by \$36.35 per head, or 27.5%. With total 1992 GIPSA-reported slaughter at 31.2 million cattle, the aggregate 1992 cost savings from the realization of scale economies from 1977–1992

Table 7. Effects of Consolidation on Slaughter Costs

Year	Source for Plant Size Distribution: Actual (LRD)	Estimated (GIPSA)
Mean industry processing cost	Per head (1992\$)	
1977	132.18	131.42
1992	95.83	96.58
1997	n.a.	90.65
2002	n.a.	85.09
Aggregate cost reduction from consolidation	Millions (1992\$)	
1977–92	1,134	1,087
1992–97	n.a.	208
1997–2002	n.a.	187

Notes: Mean industry processing cost is the weighted average of predicted values of processing costs, with plant size as the weight. Predicted values are obtained from the model summarized in tables 3 and 4, with base (1992) parameter estimates and 1992 mean sample values for factor prices, product mix, and imput mix.

[11] That industry-wide mean is much higher than the \$69.50 reported earlier for a very large plant (1.35 million head), because a considerable share of 1992 production still occurred at smaller, higher cost, plants.

[12] That is, we ask the counterfactual: what would industry-wide slaughter costs have looked like with 1992 technology and factor prices, but with the 1977 size distribution of plants?

consolidation amounted to \$1.13 billion. This consolidation was the driving force in the decline of farm to wholesale beef margins, through the realization of scale economies, analyzed by Azzam and by Brester and Marsh.[13]

Production continued to shift to larger plants after 1992. We do not have post-1992 LRD data, and hence do not know the exact plant size distribution in later years, but we can approximate it. GIPSA reports the number of plants in each size class in table 1 and the number of cattle moving through them, so we can calculate the mean plant size and the share of slaughter in each class (USDA 2004). Using the approach described above, we calculated a predicted processing cost for the mean plant in each class; the industry mean processing cost is then the weighted average of mean plant costs, with class shares as weights. We first calculated these for 1977 and 1992, to compare them to estimates based on the full plant size distributions for those years. The results, reported in the right hand column of table 7, are quite encouraging, with results that are within 1% of those based on full distributions.

We then reweighted the size classes, using the 1997 and 2002 plant size data in table 1, to calculate the continuing effects of consolidation on costs through the realization of scale economies. We continued to use mean 1992 values for factor prices, so results are in 1992 dollars. The effects of the further shift to larger plants in 1997 (replacing 1992 with 1997 weights) is to further reduce slaughter costs to \$90.65, a 6.1% decline.

Production continued to shift to larger plants in 2002 (table 1), and reweighting for that shift reduced slaughter costs further, to \$85.09 per head. In total, consolidation between 1977 and 2002 reduced processing costs by about \$1.5 billion a year (1992 dollars) by the end of the period, with almost three-quarters of the gain occurring between 1977 and 1992 (table 7). The annual rate of consolidation-related cost decline fell considerably after 1992 because consolidation slowed and because the estimated cost-curve flattens at the largest sizes.

[13] We can separately estimate the impact of 1980's wage reductions on processing costs. Labor's share of processing costs was 44%, on an average (labor, materials, and capital, in table 5). A 30% decline in meatpacking wages (the relative fall in figure 1) would then imply a 13% decline in processing costs, just under half the effect of scale economy exploitation in 1977–92.

From Scale to Concentration: Was Technology All That Mattered?

Technological change in cattle slaughter created new and extensive scale economies between 1963 and 1992, and changes in the industry's labor environment accentuated those economies. Packer exploitation of scale economies, through the construction and operation of larger plants, substantially reduced costs.

Yet that exploitation raises two questions. The first relates to the timing of the industry's consolidation. There were substantial unexploited scale economies in the 1970s, with production concentrated in many small plants. Why did consolidation not occur until later? Second, consolidation in cattle slaughter is associated with a dramatic increase in four-firm concentration, much greater than that occurred in either hog slaughter or poultry processing, which also had important emerging scale economies and large increases in plant sizes. Why did beefpacking CR4 increase so much? We turn to four other factors: complementary investments in related industries, competition, mergers, and product demand.

Complementary Investments and the Timing of Consolidation

Large plants have substantial fixed costs, due partly to capital intensity, and partly to labor practices (weekly minimum hours guarantees to production workers). As a result, short run processing costs at large plants rise sharply as volumes fall below capacity (Morrison-Paul 2001a), and packers require large and consistent flows of cattle before committing to a large plant.

Complementary developments in cattle feeding may have enabled the exploitation of new scale economies in meatpacking by ensuring the necessary livestock volumes. During the period of our analysis, cattle feeding shifted from small farmer-feedlots distributed around the country to much larger commercial feedlots concentrated in four states (CO, KS, NE, and TX), which accounted for nearly three-quarters of all fed cattle marketings by 1992, up from half in 1974, our earliest data on feedlot sizes. In turn, the largest feedlots in those states (at least 16,000 head capacity) marketed one quarter of all fed cattle in 1974, nearly half (46%) by 1992, and well over half (57%) by 2002.

For packers, a dense network of large feedlots offer assured steady cattle supplies to ensure high plant utilization, and the largest packers interact closely with large commercial feedlots. A survey (USDA 1996) of over 200,000 transactions for fed cattle in 1992 found that feedlots selling at least 32,000 cattle annually sold two-thirds of their cattle to the largest packing plants. In contrast, farmer-feedlots in the survey sold two-thirds of their cattle to small plants. All packing plants with capacities exceeding one million head are located in the four primary feeding states. Expansion of packing plants likely depended upon the complementary expansion of a network of large feedlots.

Competition

Organizational and technological factors may have combined to drive the shifts in plant size seen in our data. However, they cannot provide a complete explanation for such rapid and massive consolidation, because the measured advantages of scale are modest. For modest cost differences to lead to such rapid change, the industry must also have had strong price competition. Small, less efficient plants do not exit because larger plants have slightly lower costs: they exit because product prices fall below their own average variable costs. For product prices to be below small plant costs, they must in turn be quite close to large plant unit costs, because we find small differences between small and large plant costs, especially above 425,000 head.

Game-theoretic analyses argue that intense price competition can lead to greater concentration in homogeneous goods industries (Sutton). Although there were only a few major packers left by 1992, they purchased a largely undifferentiated product from sophisticated sellers, and analyses of cattle pricing find little evidence of market power, despite high concentration, during the period of consolidation. For example, Azzam concluded that packers had very weak monopsony power during the 1970s and 1980s—only a fraction of that exercised by a Cournot oligopsony with the same level of concentration. Morrison–Paul (2001a) found no evidence of monopsony power in cattle markets in her study of packing plants in 1992.

If pricing was competitive, then intense price competition, in Sutton's sense, may have accelerated the adjustment to scale economies and the increase in beefpacking concentration in the 1980s and early 1990s by forcing smaller, higher-cost plants to exit. Moreover, intense price competition can help to account for the labor battles of the early 1980s, because even small cost differences matter a great deal if price competition rapidly drives prices toward costs.

Mergers, Plant Size, and Concentration

Popular accounts often assume that mergers drove the industry's consolidation, but mergers have actually had a minor impact on increased concentration in beefpacking, which followed largely from increases in plant sizes among existing firms, not from mergers. We offer two sources of evidence in support. First, if mergers led to increased concentration by placing more plants under the control of individual firms, we should see increases in multiplant ownership in the industry. However, GIPSA data show that the four largest cattle slaughter firms owned 23 plants in 1980, with average slaughter volumes of 417,000 head per plant, when four-firm concentration was 28 (USDA 2004). By 2002 (with CR4 in cattle purchases up to 69), the top four-firms owned 25 plants, just two more than in 1980, but with average annual volume of 1 million head. Firms got larger, in general, because their plants got larger, not because they acquired more plants.

Second, although the leading firms each acquired other packers through merger during the period, such acquisitions were minor forces in increased concentration. Our LRD data base allows us to track ownership of plants over time. We summed the acquisition-year outputs of all cattle slaughter plants acquired by any packer during the 1977–92 period of consolidation—that is, we looked at horizontal mergers. Total output at those plants amounted to just under 7% of 1992 industry output. Expanded production by the top four were fueled by newly constructed plants and by expansion at plants that they already owned, not by acquiring large existing plants.

Demand

Particularly when one considers the contrasting trends in industry concentration (CR4) in cattle, hog, chicken, and turkey industries, it is hard to avoid the role of demand and aggregate industry production. Each industry displayed sharp increases in plant size since the early 1970s, with important emergent scale economies (MacDonald and Ollinger; Ollinger, MacDonald, and Madison).

However, CR4 in the poultry industries grew only modestly, and remained at levels that are about average for U.S. manufacturing industries. Commercial turkey meat production grew at 4% per year between 1970 and 2002, while commercial broiler meat production grew even faster, at 4.8% per year. By contrast, commercial pork production grew at 1% per year. With expanding plant sizes, little change in the extent of multiplant operation, and price competition driving out high-cost operations, CR4 in hogs rose from 34 in 1980 to 56 in 2002. Growth in commercial beef production was even slower—a 0.6% annual rate between 1970 and 2002, with sharp declines in retail beef demand driving declines in beef production in during the period of sharp concentration increase between 1977 and 1992 (Marsh). With a dramatic expansion of plant size set against falling market demand, and essentially no change in the extent of multiplant ownership, sharply increased CR4 was a likely result.

Our evidence indicates that there may have been unexploited scale economies in the 1970s, suggesting that the competitive pressures on higher-cost plants may have intensified after that period. Declining demand, and changes in management occasioned by mergers, may have also combined to intensify the industry's competitive environment in the 1980s, thereby helping to accelerate the trend toward larger plants and higher concentration.

Conclusions

The industry's consolidation in the 1980s and 1990s was initiated by technological and factor price changes favoring large plants, but we argue that it was dependent on the development of important cost complementarities in the supply chain for cattle, and may have been accelerated by the industry's competitive environment during the period. Given the extensive nature of production scale economies, the dramatic shifts in plant size of the last twenty-five years led to large savings in beef slaughter and processing costs. Exploitation of scale economies, together with actual declines in production worker wages, led to a sharp rate of decline in packer costs in the 1980s, and the slowing of those effects contributed to rising costs in more recent years.

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